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CHARACTERIZATION OF PEAT-ELECTRICAL PROPERTIES BY MEANS OF GEOPHYSICAL MEASURMENETS

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SUMMARY

Protection of peatlands in their function as storage for carbon requires information about their current state, especially about peat condition (degree of decomposition) and thickness. To test for the potential of non-invasive geoelectrical techniques, particularly the measurement of electrical conductivity (EC), we analyzed electrical properties of fen-peat- and the underlying gyttja substrates in the laboratory. Our results show significant differences between EC of peat and gyttja substrate. Additionally, the relationship of EC and water content seems to be controlled by substrate type, such as peat and gyttja material in general, and between different stages of peat decomposition in particular.

KEYWORDS: Geophysical techniques, electrical conductivity, peat-decomposition, peat thickness

INTRODUCTION

Peatlands have an important function for the storage of global carbon. These functions are reduced significantly due to the intensification of agricultural land use, which leads to mineralisation and humification processes and finally to the decomposition of peat material, going along with a loss of organic carbon. In order to protect peatlands and their function as global carbon sinks, data about the current state are required. Therefore, information about both, peat conditions (degree of peat decomposition) and thickness are crucial. Techniques to estimate such information effectively in the field are, however, still largely missing in practice.

The application of non-invasive geophysical techniques has the potential to gather this information by measuring the electrical conductivity (EC) of a peat soil, which is correlated with several peat properties. Ground-penetrating radar, measuring dielectric permittivity of a soil volume, have been used on peatlands successfully in order to determine the thickness of peat (Comas et al., 2011; Sass et al., 2010; Lowry et al., 2009). However, the application of these techniques is limited to peatlands in a natural state that show low degrees of decomposition. In contrast techniques, which measure EC of the soil, have not yet been applied frequently to peatlands (Slater & Reeve, 2002; El-Galladi et al., 2007) and never on degraded fen soils that show very high degrees of decomposition. In order to fill this gap, we evaluated the application of geophysical techniques, which measure EC of a soil volume. As a first step, we therefore analyzed the electrical properties of different peat substrates.

According to site-specific conditions, EC correlates with EC of soil solution (EC_e), organic matter, water content and bulk density. The correlation of EC with organic matter content is due to its high cation exchange capacity (CEC) (Slater and Reeve, 2002; Triantafilis et al., 2002). Peat material is rich in organic matter and, thus, CEC and EC_e, which is correlated with CEC, are important factors influencing EC at peatlands. Moreover, the CEC of peat increases with increasing decomposition (Hobbs, 1986; Seybold et al., 2005, Asadi et al., 2011). Consequently a correlation between CEC and the degree of decomposition can be assumed. There is only one study on the relationship of peat humification and EC, describing higher values of EC at higher degrees of decomposition (Asadi and Huat, 2009). Most of the studies, which were conducted on peatlands, correlated EC with peat thickness, without explaining the physical reasons for this relationship in detail (Slater and Reeve, 2002; Triantafilis et al., 2002). Additionally, less is known about the quantities of electrical properties of peat at different degrees of decomposition and about the underlying gyttja substrates.

The objective of this study is to analyse the electrical properties of peat and gyttja substrate from a fen soil in the laboratory. In order to reveal the dimension of EC occuring in the field under different water regimes, gyttja and peat substrates at high and low degrees of decomposition will be measured over a wide range of water content. Moreover, basic principles of the relationships between EC and water content will be investigated. Finally, we explore differences in EC between peat and gyttjas in order to assess the applicability of EC methods for estimating the peat thickness in the field.

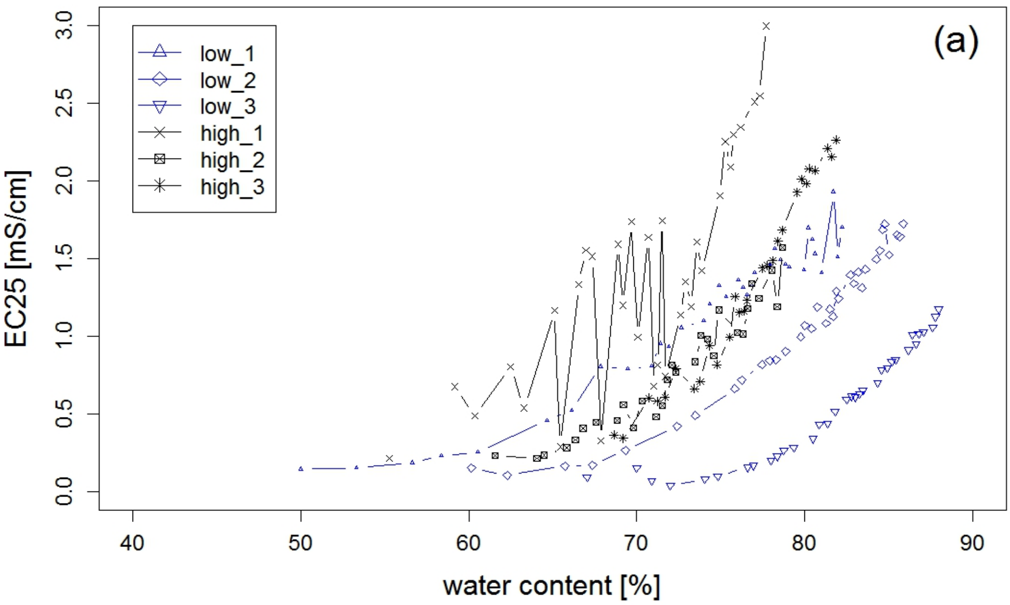
MATERIALS AND METHODS

Undisturbed samples were taken from a fen soil in Brandenburg in North East Germany. The field survey was conducted at the same location. The examined fen soils were build up of layers with different degrees of decomposition of the peat material. Six peat samples were taken, three showing high (H10), and three showing low (H2-H4) degrees of decomposition (classification after von Post (1922), ranging from H1-H10). High degrees contain less-, low degrees more content of organic carbon. Additionally, six gyttja samples were taken. Following the ‘German classification’, which has two main subdivisions for gyttja substrates, three contained high- (‘organic gyttja’), and three contained low content of organic carbon (‘mineral gyttja’).

EC of the peat substrates was measured in the field and in the laboratory by means of geoelectrical techniques.The peat thickness at the study site was known and, hence, the depth of penetration for electrical measurements was determined accordingly. The principles used to measure EC are the same for field and laboratory analysis, but the measured soil volume differs. Through two electrodes at the surface an electrical current is introduced into the soil and the difference in current flow potential is measured at two further electrodes, which are placed between the current electrodes (Wenner-Array). According to the measured difference in potential, which is a function of the electrical properties of the soil, an EC can be calculated. In order to assess EC at different water content, the measurements in the laboratory were conducted over a period of almost two months, in which the samples were gradually air-dried and the decrease in gravimetric water content was determined simultaneously. As EC is influenced by temperature, all values were converted to a reference temperature of 25°C (expressed as ‘EC_{25}’ after McNeill, 1980).

RESULTS

EC_{25} as a function of percentage water content is shown in Figure 1a and 1b for peat and gyttja samples, respectively. The relationship between EC_{25} and water content differs considerably between both substrates, indicating generally higher levels and ranges of EC_{25} for peat (Fig. 1a), particularly if compared to the mineral gyttjas (Fig. 1b). Within the gyttja samples, the relationships differ between the types of gyttja. The mineral substrates show less change in EC_{25} at decreasing water content, whereas the organic gyttjas reveal a substantially different behavior (Fig. 1b), namely a rather hump-shaped response of EC25 to water content.



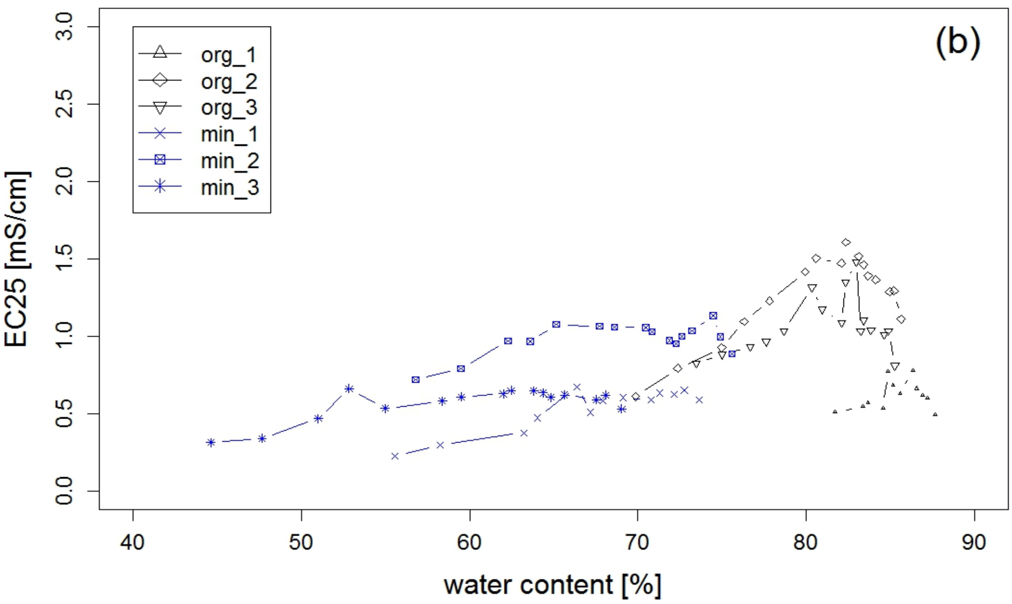


Fig. 1. EC_{25} as a function of the water content, for peat with low and high degrees of decomposition (a) and for mineral and organic gyttja, respectively (b).

Table 1 summarizes results of EC_{25} measurements in the field and in the laboratory for the different substrates. EC_{25} was significantly higher (Wilcoxon test, p=2,36e-06) in peat (median 0.99 mS/cm) than in mineral gyttjas (median 0.81mS/cm). The differences decreases when EC_{25} of peat and gyttjas in general were compared (p=0.071), without separating the two types of gyttjas. Between the two different degrees of decomposition of the peat samples no significant difference could be observed. These findings were supported by the results of the field survey.

Table 1. EC_{25} values for field and laboratory measurements. Peat substrates with high and low degrees of decomposition and gyttjas with low ('min_gyttja') and high content of organic carbon ('org_gyttja')

	n	*min.*	*max.*	*mean*	*median*	*sd*
field						
peat	572	0.67	3.14	1.67	1.62	0.5
laboratory						
peat	224	0.04	3.00	0.99	0.99	0.58
gyttja	85	0.22	1.61	0.86	0.81	0.33
peat_high	120	0.08	3.00	1.06	0.99	0.62
peat_low	104	0.04	1.93	0.91	0.95	0.52
org_gyttja	48	0.61	1.61	1.10	1.05	0.23
min_gyttja	41	0.22	0.78	0.57	0.60	0.11

DISCUSSION

EC_{25} of examined peat substrates (ranging from 0.04 up to 3 mS/cm, with an average of 0.99 mS/cm) are very high, compared to those reported in the literature (e.g. 0.05: Comas et al., 2004; 0.04-0.077: Slater and Reeve, 2002). Most of these investigations were on natural peatlands with low decomposition, whereas our samples were derived from fen soils, which partly showed very high degrees of peat degradation. Consequently, we can state, geophysical measurment on degraded fen soils is a new field of inquiry, because these sites show different electrical properties. Moreover, an application of geophysical techniques seems at such high values of EC particular reliable.
The difference between EC_{25} of mineral gyttjas and peat is significant over a wide range of water content. These findings were supported by the results of the field survey: along the investigated profiles, the highest values of EC_{25} (the equivalent of the lowest values of resistivity) (Fig. 2) are correlated with the thickness of the peat layer (upper two meters) as it was described by conventional coring techniques. Hence, the application of EC_{25} measurements seems to be appropriate for estimating the depth of the interface between peat and gyttja (i.e. peat thickness).

Comparison of the relationships between EC and water content between peat and gyttja substrates, and especially between mineral and the organic gyttjas reveals completely different characteristics (Fig. 1a and b). Initially, EC_{25} of the organic gyttjas increase with decreasing water content until a certain threshold, after which EC_{25} is decreasing again. In contrast, the mineral substrates decrease with decreasing water content, equally over the whole range of water content. This behavior was similarly observed by Durlesser (1999), who examined soils with varying content of clay and who ascribed this phenomenon to an initial rise of concentration of the ions in the soil solution as a consequence of decreasing dilution.

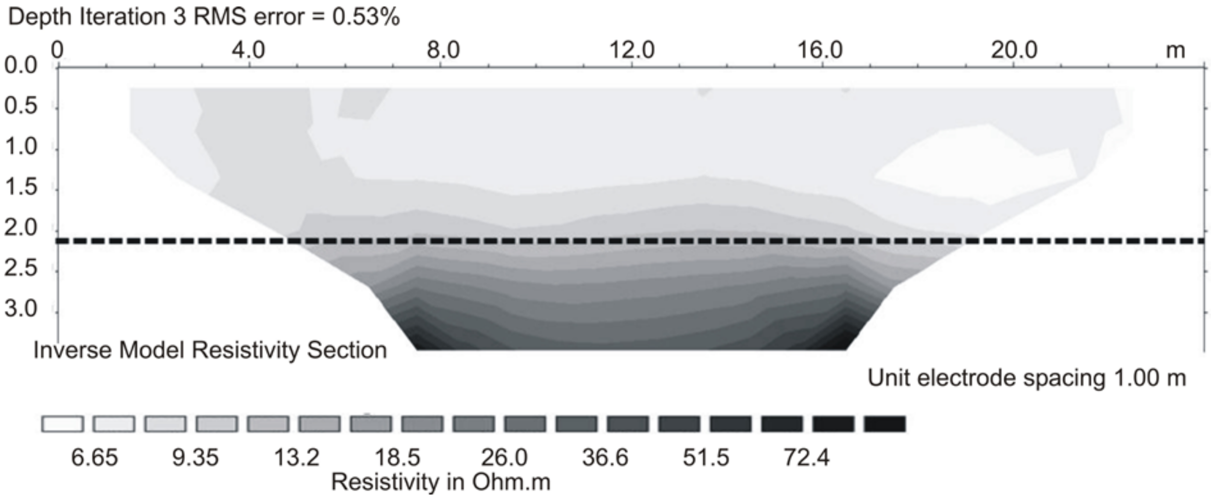


Fig. 2. Profile of resistivities calculated from field data, light colors indicating high- and dark colors low values of EC (EC is the inverse values of resistivity). The black dotted line shows the interface between peat and gyttja, determined by conventional coring techniques.

This process continues until the decrease in water content reaches a level that causes a disconnection of a continuous pathway for the electrical current, which in turn leads to a new decrease in EC_{25}. In our study, this behavior can only be observed at organic gyttjas, which typically show higher values of CEC, and, thus, EC_e in comparison to mineral substrates. The significant difference in EC_{25} between mineral and organic gyttjas (Table 1, Fig. 1b) can presumably be ascribed to the higher values of CEC and EC_e of the organic gyttjas.
The shape of the graphs of the peat samples seems to be controlled primarily by the pore size distribution. Due to the high porosity of the peat material, EC_{25} can be a function of the pores filled with water. This is especially the case for sample 'high_2' (Fig. 1a). Its high variability could be caused by an irregular secondary pore system, which was observed in the field for that sample. Whether these pores were filled with water or air during the drying process, lead to different values of $EC_{25.}$

Within the peat samples, higher degrees of decomposition correspond to a greater range of EC_{25} (Table 1). Even though EC as a function of the degree of decomposition of tropical peat were reported by Asadi and Huat (2009), we could not show a significant difference in EC_{25} between both degrees of decomposition in our data. On the one hand, this can be explained by the fact that sample 'low_2' and 'low_3' were taken from sites, that had been fertilized just before sampling, which had lead to a higher level of EC_e and hence of EC_{25}. On the other hand, we only analyzed two different degrees of decomposition with a replication of three, possibly not enough to detect differences in EC_{25} between decomposition states.

Summarizing the above, we could show that EC on degraded peatlands are higher as those on peatlands in a natural state. Furthermore, we found significant differences in EC_{25} between peat and the underlying mineral gyttja substrate over a wide range of water content. The shape of the relationship between EC_{25} and water content is supposively controlled by ionconcentration of soil solution (EC_e) and porosity. This relationship seems to be, moreover, a function of the type of gyttja and degree of decomposition, respectively.

In order to further explore the effect of decomposition on EC, we are currently measuring EC_{25} at a broad range of peat substrates, which show different degress of decomposition (H1-H10), in the laboratory. Here, one key issue is the quantification of other peat soil properties affecting EC_{25}, such as CEC, organic carbon, EC_e and bulk density. For this purpose, we choose sites at which we could better control for additional effects like fertilization or concentration of calcium carbonate, in order to account for our to date still limited understanding of such effects.

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